NRL Report 7763

Proceedings

Waldorf Conference on Long-Range Geographic Estimation of Lightning Sources

September 11-16, 1972

Sponsored by

International Commission on Atmospheric Electricity

Hosted by

Office of Naval Research
Naval Research Laboratory

July 1974

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NRL Report 7763	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PROCEEDINGS OF THE WALDORF CONFERENCE ON LONG-RANGE GEOGRAPHIC ESTIMATION OF LIGHTNING SOURCES — SEPTEMBER 11-13, 1972		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R.V. Anderson, R.B. Bent, H. Dolezalek, F.J. Kelly, Program Committee		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Research Laboratory Washington, D.C. 20375		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 83Z00-01
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE July 1974 13. NUMBER OF PAGES 512
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Distribution of this document is unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Lightning	Waveguide propagation	Omega	Global thunderstorm activity
Atmospherics	Schumann resonance	Multimodal propagation	
Sferics	Electric field	Atmospheric electricity	
VLF	Severe storms	Climatology	
Storm detection	Thunderstorms	Meteorology	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Preface

The Waldorf Conference on Long-Range Geographic Estimation of Lightning Sources was held in sessions 1 to 4 and 6 to 8 in the building of the Office of Naval Research on 800 North Quincy Street, Arlington, Virginia, 22217, on 11 to 13 September 1972, interrupted by session 5, which was an excursion to the Waldorf Observatory of Atmospheric Electricity of the Naval Research Laboratory, at Waldorf, Maryland, in the late morning and early afternoon of 12 September, including a luncheon at the Collingwood Restaurant in Mt. Vernon (the old tea house

(Continued)

20. Preface Continues

of the George Washington estate). On 14 and 15 September, workshop sessions were held at the Waldorf Observatory, followed by a concluding session at 1812 Drury Lane in Alexandria, Virginia.

Most papers presented during the first three days of the Conference are reproduced in these Proceedings. Some authors who gave presentations did not find the time to prepare a full text paper; in these cases, only the abstracts are reproduced here. Some authors changed the title of their papers slightly; others included with the agreement of the Program Committee, remarks which they had made during the discussion following their presentation. For example, H. Volland gave a second paper during the Workshop Session on Thursday, in which he responded to some points made in other papers and in the discussion. He was then asked to combine his original paper and the short ex-tempore one he gave at Waldorf, into one document. Unfortunately, the discussions themselves could not be recorded. In one case, the presentation of the Conference is now split into two papers by the same author. As a special addition, to amplify the report given by G. Hagn, the full text of F. Horner's paper from the XVI General Assembly of UGGI (which was held shortly before the Waldorf Conference) is included at the end of these Proceedings.

All papers are reproduced in this volume in the form as they have been submitted without any editorial work.

December 1973

PREFACE

The Waldorf Conference on Long-Range Geographic Estimation of Lightning Sources was held on September 11-16, 1972. Sessions 1 to 4 and 6 to 8 were held in the building of the Office of Naval Research, Arlington, Virginia on September 11 to 13. Session 5 was an excursion to the Waldorf Observatory of Atmospheric Electricity of the Naval Research Laboratory at Waldorf, Maryland, in the late morning and early afternoon of September 12 and included luncheon at the Collingwood Restaurant in Mt. Vernon. Workshop sessions were also held at the Observatory, on September 14 and 15, followed by a concluding session on the premises of the International Commission on Atmospheric Electricity, 1812 Drury Lane, Alexandria, Va.

The Conference was sponsored by the International Commission on Atmospheric Electricity (President: L. Koenigsfeld; Secretary, H. Dolezalek) as part of their program to monitor global lightning activity for the atmospheric electricity ten-year program. The program was organized by a committee of R. V. Anderson, R. B. Bent, H. Dolezalek, and F. J. Kelly of the Office of Naval Research and the Naval Research Laboratory and was hosted by the Naval Research Laboratory.

Most of the papers presented during the first three days of the Conference are reproduced in these Proceedings. Some authors who gave presentations did not find time to prepare the full text; in these cases, the abstracts are reproduced here. Some authors changed the titles of their papers slightly; others, with the agreement of the Program Committee, included remarks which they had made during the discussion that followed their presentations. For example, H. Volland gave a second paper during the Workshop Session on September 14 in which he responded to some points made in other papers and in the discussion. He then combined the formal presentation and the extemporaneous one into one document. (Unfortunately, the discussions themselves could not be recorded.) In another case, the formal Conference presentation was split into two papers by the same author. As a special addition, to amplify the report given by G. Hagn, the full text of F. Horner's paper from the XVI General Assembly of UGGI, held shortly before the Waldorf Conference, is included at the end of the Proceedings.

All papers are reproduced in this report as they were submitted, without being edited. The Program Committee members handled all arrangements necessary for publication.

The Workshop Sessions are not recorded herein, since the discussions though beneficial, were too detailed and specialized to merit distribution beyond the actual users of the Atmospherics Analyzer.

December 1973

Welcoming Remarks

Dr. R. R. Goodman
Associate Director of Research
Naval Research Laboratory, Washington, D.C. 20375, USA

Opening Address

Prof. Dr. L. Koenigsfeld
President,
International Commission on Atmospheric Electricity
17, Rue de l'Etat Tiers; B-4000 Liège, Belgium

Chairmen of Sessions

Session 1: Review of Methods for Long-Range Geographic Estimation of Lightning Sources
Dr. R. B. Bent,
Atlantic Science Corporation, Indialantic, Florida, USA

Session 2: The Physics of Sferics Emitters, Lightning
Dr. R. E. Orville
Department of Atmosph. Science, State University of New York, Albany, USA

Session 3: Propagation of Sferics Over Long Range
Dr. G. Jean
Space Environment Laboratory, NOAA, Boulder, Colorado, USA

Session 4: ULF, SLF, & EFL Methods for Localization of Thunderstorms
Dr. E. T. Pierce
Stanford Research Institute, Menlo Park, California, USA

Session 5: Excursion to Waldorf Observatory

Session 6: General Results Obtained with Various Systems
Hans Dolezalek
Office of Naval Research, Arlington, Virginia, USA

Session 7: The Analyzator for Atmospherics as Developed in Leningrad
(Session omitted)

Session 8: Results Obtained with the Heinrich-Hertz Institute Atmospherics Analyzer
R. V. Anderson
Naval Research Laboratory, Washington, D.C., USA

Chairmen of the Workshop Sessions at Waldorf and Alexandria:
R.V. Anderson, H. Dolezalek, Dr. W. Harth, G. Heydt, Dr. T. Takeuti

CONTENTS

WELCOMING REMARKS

On the part of the Office of Naval Research and the Naval Research Laboratory, we wish to welcome you to the Washington area; and we hope that you have an excellent meeting. I'd like to explain, briefly, the relationship between the Office of Naval Research and the Naval Research Laboratory. The Naval Research Laboratory is actually part of the Office of Naval Research. The Office of Naval Research has two sides to its research program. One is the contract research program that many of you are familiar with, and the other is this laboratory, the Naval Research Laboratory. Both report to the Chief of Naval Research. Thus, it is really not correct to say "The Office of Naval Research and The Naval Research Laboratory." We are very proud of the organization that we work for.

We at the laboratory and in the ONR contract program are dedicated to naval research but also, and it's not to be forgotten, are dedicated to basic research. The meeting here exemplifies the kind of relationship that we like to see between our laboratory and the worldwide community in a field. I have reviewed with Mr. Anderson the origins of this meeting and the events that ultimately led to this conference. You and the general field of the earth sciences have common concern and it is one that I view as extremely important. It is that of the means to have efficient data exchange. It is essential to solve this problem to find a means and a format that is acceptable to everyone in the community. I hope that you are more successful in your meeting in the next few days than we have been in the field of oceanography.

I look at your program with envy. It's a good mixture of formal papers and work sessions. I believe that, if it is possible, we ought to use this kind of a distribution of work sessions and papers as a model for meetings in the future. I have two more conferences to attend this week, and neither one has the kind of work sessions that you have here. I must apologize to Professor Polk for that comment. I wish to thank you for inviting me to open your conference. I hope that your work sessions and your formal papers go well and that the meeting is a success. Thank you.

Ralph R. Goodman

OPENING ADDRESS

Following the request of Dr. Berman in his letter of 16 February 1972, we are very happy to sponsor this conference on V.L.F., variations and propagation of these frequencies.

These researches needing investigations of many countries and at the international level, this meeting must have the help of an international commission on atmospheric electricity and it is why we have decided to sponsor this conference.

Furthermore, we hope that the results which are going to be examined during the meeting will bring, at a larger scale, a more general view on repartition of storms in the world and will allow us to obtain a better theory. This might bring some changes in the classical theory of atmospheric electricity.

The objective of the conference is an assessment of the present possibilities and potentials to work towards the aim of a global lightning monitoring system.

As it seems the method of dispersion of electromagnetic waves in the atmosphere hold the greatest promise to approach the aim and a network of stations. With this network, we hope to obtain good results and to supply a good theory. This is the aim of this conference and I hope to have practical results after the discussions.

As regards atmospheric electricity, it is a capital problem and we will reach great improvement if we obtain good results thanks to a good international co-operation.

It is indeed what I hope and I sincerely wish that during this conference we will have a valuable work, interesting discussions and that everything will be settled perfectly.

L. Koenigsfeld

The Waldorf Conference - an Introduction

by Hans Dolezalek, Office of Naval Research, Arlington, VA 22217 USA

It was E. T. Pierce who at first made me see the peculiar situation that many a meteorologist did not acknowledge information on the electrical hazards related to thunderstorms as being a "meteorological parameter". Going back to the outspoken or not-outspoken mandate people are giving their meteorologists in the weather services, however, we hardly can fail to see that information on the dangers, benefits, and damages in many varied forms stemming from the fact that the meteorological event called "thunderstorm" may generate lightning is part of the expectations to be derived from that mandate. If we agree on this, we probably must conclude that - whether the officials in the meteorological profession do acknowledge it or not - part of that mandate is the obligation for scientists who know something about lightning in the broadest sense to make such knowledge available. Such obligation is visible in this volume of the proceedings of a conference which dealt with some aspects of obtaining information on the locality and time where and when lightning does occur.

To some extent, many of us are harboring the feeling that man can "out-engineer" nature or the environment - a multi-faceted concept which has its haunting overtones in a period of increasing ecological awareness, but here meant only to express the feelings that the dangers of nature can be overcome by planned counteractions; and the conclusion derived from such feelings that with progressing technology natural hazards become less and less menacing. Such conclusion has its drawbacks because technological development also creates often new dependencies, mostly because it may lead to a specialization which is not adapted to the full spectrum of natural possibilities: to start the motor of my car on a cold and stormy winter morning can easily be more difficult than to mount a horse and ride it out. While the number of people killed by lightning is decreasing in countries where urbanization of the population is in progress, it still about equals the number of fatalities caused by tornadoes in, e.g., the contiguous United States of America; while less people than did a hundred years ago still depend in their work on the absence of lightning danger, we even in our day experience shut-downs of professional activities because of such danger; while more aircraft can fly over a thunderstorm than they could thirty years ago, the number of airplanes - both civilian and military - who cannot or are not supposed to fly through or over a thundercloud, is greater now than it was thirty years ago, and is increasing. In fact, we would find more and more of such unexpected vulnerabilities in our modern technique the more we look. Making the airplanes faster and larger requires better information on lightning danger, going from metal skins of airplanes to the "more modern" fiberglass or boron-fiber structure makes the plane much more vulnerable from lightning; replacing functions of the pilot by electronic gear - a necessity increased by increased speed - opens new dangers from the magnetic and electric fields generated by lightning ......

we now find that lightning hazard to overland power lines is larger than concluded from many years of earlier research .....plastic houses do not offer the protection we had in structures which involved steel or even wood unless we pay special attention to this hazard....and we find it necessary to educate the public better on the danger from lightning than has been done before. Work is being done to find remedies to de-electrify clouds, but although this does look promising, it will always be a rare case in which such effort will be seriously undertaken. In conclusion, information on the occurrence of lightning - a necessity for any attempt to predict it - is wanted.

We also want it for scientific reasons. Knowledge on the electrical circuits and balances in the atmosphere probably requires an incessant monitoring of lightning activity on a world-wide scale; some of us hope that by incessant monitoring of tropical thunderstorm activity we may gain information on the heat input into the general global atmospheric circulation; understanding of the process of lightning initiation and development may receive some assistance from a better knowledge under which situations lightning does occur; the attempts to understand development of thunderclouds, and maybe of tornadoes, may be helped if we can measure the lightning activity. Admittingly, some of this is speculative, but I hope it is the type of speculation which usually stands at the beginning of a scientific endeavor. Did lightning play a role in the development of the early terrestrial atmosphere, or even of life on our planet - does it have a role in the Venusian atmosphere, are there lightning-like sparks on Mars, what about Jupiter? Was lightning the source of fire and did it regulate in this way the growth and decay of forests - still more speculations.

The attempt to monitor lightning, in addition to the information provided by eye and ear, began shortly after Dalibart and Franklin established as a fact that lightning is an electric spark: by connecting his frog legs to a kind of antenna and by grounding the other part to a well, Aloysius Galvani already in 1791 observed a jerk in the frog leg when there was a lightning. Obviously, this was caused by the "electrostatic member" in the well-known, over-simplified formula

$$E_v = \frac{1}{4\pi\varepsilon_0}\frac{2h}{r^3}Q + \frac{\mu_0 c}{4\pi}\frac{2h}{r^2}\frac{dQ}{dt} + \frac{1}{4\pi c}\sqrt{\frac{\mu_0}{\varepsilon_0}}\frac{2h}{r}\frac{d^2Q}{dt^2}$$

Here, E_v is the vertical component of the electric field, generated by a vertical dipole with 2h the distance between the two charges Q, at a distance r from the dipole ($r \gg h$); t, c, ε_0, and μ_0 are time, velocity of light, capacitivity and "inductivity" (permeability), respectively. (For a derivation of this formula from the Maxwell Equations, given by H. W. Kasemir, see Appendix III.A of Israël 1973) *).

This formula, which can be written in several different forms (and also

*) for the correct formula, valid also for close distances, see McLain & Uman 1971

looks different in different systems of dimensions and units), is convenient, because in an approximation it allows a separation of purely electric ("electrostatic"), magnetic and electromagnetic effects and shows how these vary with distance r.

For a more detailed discussion on these effects from lightning, and for reports on former measurements and networks of stations, we refer to sections (§) 67, 68, and 91 and Appendix I/III.E of Israel 1973, and to the many references quoted there. More references are to be found quoted on pages IUGG 359/360 of Dolezalek 1970 and in the bibliographies of papers in this volume.

We see from the formula that the electric and magnetic fields as represented in the first and second members of the formula decay relatively quickly with distance while the electromagnetic effects of the third member should be detectable over a much wider area. However, this formula is an approximation only for the direct propagation along the ground (ground wave, zero mode), not accounting for the fact that some of these electromagnetic waves can use other modes of propagation, too. The frequency emitted from lightnings covers a wide range from less than 1 Hz well into the tens of megahertz. Waves with low frequencies are refracted by the ionosphere and may reach a receiver via one or more "hops" (higher modes) - and the so-called "Schumann Frequencies" of about 8 Hz and higher harmonics excite the resonance of the earth-ionosphere cavity and can be measured anywhere on earth.

Consequently, the electric and magnetic effects and the higher frequencies of the electromagnetic emission can be used to monitor lightning activity only within limited ranges (20 to 250 km, depending on antenna height, receiver threshold, frequency) and if a larger area is to be covered, a relatively dense network of stations is required. The higher frequencies of the electromagnetic emission penetrate the ionosphere and could - in principle - be used for lightning tracing from satellites passing overhead. For "Long-Range Geographic Estimation of Lightning Sources" we are restricted to the VLF and ELF ranges.

Obviously, for a determination of the geographical coordinates of a lightning source from receivers more than 400 km away, we shall need two parameters: the direction of the lightning as seen from the receiver, and the distance between lightning and receiver. (We are not considering here the monitoring of lightnings from satellites). The distance could also be computed if we have the direction to the lightning from two or more receiver stations located sufficiently apart and not on one straight line with the lightning - this method is often called "triangulation". Vice versa, knowing the distance from two separated stations also could give the direction with a certain degree of accuracy and not always unambiguous. As far as I know, this has never been tried, for a good reason: the direct measurement of the distance is by far more difficult than the determination of the direction (azimuth).

In the following, we consider only the VLF range, from 3 to 30 kHz. Direction of the incoming sferic is mostly determined by either a cross-loop antenna receiving the magnetic vector, or by an array of stations and comparing the time of arrival - the latter method being more complicated but allowing higher precision. There are a number of problems with both techniques, and it is sometimes difficult to avoid wrong results because of disturbing factors in the neighborhood of the receiver. For a description of some of the methods applied, and of networks which used the direction finding for a triangulation to get the locality of the lightnings see again the references quoted above.

The United States Air Force has maintained, in the 1950's, two station networks for triangulation, at first a smaller network and then a larger one. Details have remained unpublished except for a number of government reports (see for these USAF 1950's). The results from this experiment were good. Very seldom there was a thunderstorm reported by ground observers which was not "seen" at the same time by the stations of the network, but there were many more thunderstorms recorded by the stations than reported from weather and other observatories which relied on optical and/or acoustical observation. I did not really find out why this experiment was discontinued; as it seems, at the time when equipment should have been replaced because of wear and because better electronics means became available, funding was difficult to get and not enough for the renewal. It may also be mentioned that the method of triangulation is a rather complex one: sources which are seen by several stations must be identified at each one and a relatively large amount of incessant communication between the stations is required.

At this point, we may briefly discuss some of the problems which still beset the task of lightning monitoring. During the 1950's, no method for direct measurement of the distance seemed to be practical (although several had been tried) so triangulation was still necessary, and that certainly was a shortcoming. However, there were others, too. Sometimes, a thunderstorm was located in an area where according to the weather reports there were no clouds at that time. This was obviously due to some error in the determination of the direction. Then, now and then reports were heard that somebody has received sferics from areas with snowstorms, from which no thunderstorms were reported. It is difficult to see how meteorological processes other than lightning might generate sferics, but a suspicion remains. Another problem is one of economy: we have a relatively dense network of radar stations, and the question is obvious whether these could not be used for thunderstorm monitoring. A radar scanning the horizon will only rarely detect a lightning, but it will easily see the accumulation of echoes typical for cumulonimbus clouds. Whether these are recognizable as active (electrically active, that is) thunderclouds must be asked. Hiser (1973) has shown that the strength of the radar echo is not a reliable information on thunderstorm activity. By observing the height extension of that echo, the probability of correct detection may be improved. It remains, however, the fact that the range of radar is limited, and for this reason we do not have to deal here with these possibilities more in detail. The application of over-the-horizon radar for lightning detection is not very promising either, since at the radar frequencies the signal strength of the emitted sferic is not large. However, we are only beginning to learn more about the electric, magnetic, and electromagnetic emissions from lightning - and the last word is probably not yet spoken. The Fifth Conference on Atmospheric Electricity (Garmisch-Partenkirchen, September 1974) will bring more discussion on this.

At the time when the USAF experiment reported above came to an end, the situation was about as follows: the need for a direct estimation of the distance was obvious, only then could one hope to get a one-station method for the localization of lightning for a rather wide area (estimated to have a radius of around 10Mm, depending on the geomagnetic coordinates of the direction and on the time of the day.) Methods to do this were known, theoretically and with some amount of experimentation. All these methods were rather complicated, and the number of observable parameters was bewildering. Again, only a method could be successful which could be operated by untrained personnel and permitted hope for later automatization and computer handling.

One of the groups which tried to investigate these problems was centered in Germany, and the names Frisius, Harth, Heydt, and Volland - given here in alphabetical order - are often quoted in this connection. They used direction finding by cross-loop antenna, and for the distance finding investigated the fact that VLF waves have a kind of dispersion in the atmosphere-ionosphere system. That means that two different frequencies emitted by the lightning at the same time would arrive at a distant receiver with a slight difference in time (micro-seconds), this difference increasing with distance. It became quickly known that a statistical approach would be needed: the lightning does not transmit as an ideal and perfectly vertical antenna would do - but there was (and is) hope that by combining the various lightnings of a thunderstorm conditions would improve. However, with this object we are already in the midst of the discussions of this conference, and I do not want to go into more details on this.

A similar method, also applying VLF sferics, has been used by the USSR Hydrometeorological Service in Leningrad and the names B.K. Inkov, T.V. Lobodin, L.G. Makhotkin and Solov'yev have become known in this regard. - Others have tried even longer wavelengths, in the ELF (or SLF) ranges with at least some success; and a combination of VLF and ELF has been developed by K. Sao and H. Jindoh at Toyokawa. These methods seem to require larger antennae and may encounter some difficulty for oceanborne receiving stations. - The application of Schumann resonances for obtaining a measure of global lightning activity and also finding the main activity center has successfully been investigated by Ch. Polk and others. New reports may be expected at the Fifth Conference on Atmospheric Electricity.

How do we obtain a global coverage of all lightning activity centers at any one time? Obviously, any method to achieve this should give the location of the centers. This would avoid duplication of counts and give better confidence that no large areas have been left unmonitored. E.T. Pierce has suggested to locate sferics stations around the globe on about eight places where local thunderstorm activity is low (to avoid local disturbances) and all within the tropics. Islands such as St. Helena, and deserts, would be ideal locations for such stations - and in spite of difficulties of logistics and cost we still hope that one day such a network can be achieved. At the present time, we do not have high hopes of becoming soon able to install such a network, and we have to look to another possibility. A beginning which has some promise was made by the offer of the Heinrich-Hertz-Institute in Berlin to equip a number of stations with identical "Atmospherics Analyzers" which are the result of the work done by Volland, Heydt, Harth, Frisius, as quoted above. These stations are geophysical observatories which are interested in using these instruments for their own, much varied, purposes, but agree to collaborate with the other stations of this network for purposes of research and global monitoring. At first, such stations were installed at Berlin, Germany; Toyokawa, Japan; San Miguel near Buenos Aires, Argentina; and Waldorf, near Washington, D.C., USA. A slightly different station on the Stockert near Bonn also collaborated and will continue doing so. Since the Waldorf Conference, a new station near Toronto (Canada) and at least one new station in Argentina have been installed; negotiation for additional stations are prepared for locations in Antarctica, Australia or/and New Zealand, India, South Africa, West Africa - and maybe another portable station which can be set up for a limited time at various places. More definitive plans for this may be considered during a specail meeting at the occasion of the Fifth International Conference on Atmospheric Electricity - and some form of cooperation will be suggested with stations operating on similar principles elsewhere.

While expanding the network, the degree of automatization is also expanded by research and experiments made at several of the stations now in operation. Quite a number of special experiments using the various stations have been carried out, some in relation to the Atmospheric Electricity Ten-Year Program, and many others are planned. Comparisons with weather maps and satellite pictures are, of course, standard procedure.

After the initial stations of Berlin, Waldorf, Toyokawa, San Miguel, and Bonn had been in operation for about one year, several co-workers suggested a meeting to discuss possibilities and problems of this effort. This then initiated the idea to use such a meeting for a discussion of methods for long-range geographic estimation of lightning sources on a more general basis. The International Commission on Atmospheric Electricity, recognizing that this effort constituted a true example of international scientific cooperation as stated as one of their objectives, agreed to sponsor such a conference, and the Office of Naval Research and the Naval Research Laboratory agreed to host this Conference. I see it as a step in an effort to establish a global coverage in the old attempt to obtain the lighntning activity, based on realistic possibilities as given by present knowledge, available instrumentation and within present-day financial capabilities. It will not be the last attempt in this direction, I hope (and I expect that later attempts will have even better facilities) - it is the first one which promises to give useable results within a reasonable time after so many decades of theories and insufficient starts.

References:

Dolezalek, H., 1970 : Atmospheric Electricity (part of the US National Report UGGI at the occasion of its XV General Assembly, Moskva, USSR, 1971). EOS, Transactions of the American Geophysical Union, Volume 52, no. 6.

Hiser, H.W., 1973 : Sferics and Radar Studies of South Florida Thunderstorms. J Appl. Meteorology 12:479-483

Israël, H., 1973 : Atmospheric Electricity, volume II: Fields, Charges, Currents. Jerusalem 1973, xxv, 796 pp. (A) Israel Program for Scientific Translations, Cat.No.1996; (B) National Technical Information Center, Springfield, Virginia, 22151 USA, No.TT67-51394/2. Sections 67-69 and Appendix "I", III E.

McLain, D.K., and M.A. Uman, 1971 : Exact expression and moment approximation for the electric field intensity of the lightning return stroke. J.Geophys.Research 76 : 2101 - 2105.

USAF, 1950's : "Final Report on the AWS Sferics Evaluation Project (1951), Headquarters Air Weather Service, Washington, 25, D.C. Technical Report 105-102, August 1954

"Use of Sferics in Analysis and Forecasting," Department of the Air Force, Air Weather Service Manual 105-38, 1 March 1953

"Final Report Project Tornado-Sferics," Detachment 4 (Severe Weather Warning Center), 4th Weather Service (MATS), 1959

"Final Report Project Tornado-Sferics," Detachment 4 (Severe Weather Warning Center) 4th Weather Group, Air Weather Service (MATS), 1958

"Final Report Project Tornado-Sferics," Detachment 25 (Severe Weather Warning Center), 6th Weather Squadron (Mobile), 4th Weather Group, Air Weather Service (MATS), 1957

"Final Report Tornado-Sferics," Severe Weather Warning Center, 6th Weather Squadron (Mobile), Tinker Air Force Base, Oklahoma, Season 1956

"Final Report Tornado-Sferics Season 1955," Severe Weather Warning Center, 6th Weather Squadron (Mobile). Tinker Air Force Base, Oklahoma

"Final Report Tornado-Sferics Season 1954", Severe Weather Warning Center, 6th Weather Squadron (Mobile), Tinker Air Force Base, Oklahoma

I.

Review of Methods for Long-Range Geographic Estimation of Lightning Sources

Monday, 11 September 1972, 0840 - 1200 EDT, Arlington, Virginia

Chairman: R. E. Bent

Papers presented:

"A Summary of the Session on Thunderstorm Location by Radio Methods at the XVIIth General Assembly of the International Union of Radio Science (URSI) Warsaw, Poland, August 1972"	G. H. Hagn
"A Review of Techniques and Problems in the Long-Range Localization of Lightning"	G. Jean (Abstract only)
"Canadian Interest and Activity in Lightning Location"	R. C. Murty
"Present status of the study on direction finding and location of atmospherics at the Research Institute of Atmospherics"	K. Sao, A. Iwai, T. Takeuti, T. Kamada
"Critical Comparison Between Single Station Techniques of Locating Thunderstorm Areas"	Hans Volland
"An Instrument to Digitize the Individual Sferics Parameters Provided by the Atmospherics Analyzer at Waldorf, Maryland"	R. V. Anderson
"Digital Data Presentation for Spherics Analysis"	Bodo W. Reinisch

A Summary of the Session on Thunderstorm Location by Radio Methods at the XVIIth General Assembly of the International Union of Radio Science (URSI) Warsaw, Poland, August 1972

by

G. H. Hagn
Telecommunications Department
Stanford Research Institute
Arlington, Virginia 22209

ABSTRACT

This paper summarizes the review paper given by Dr. Fred Horner before Commission VIII at the XVIIth General Assembly of URSI. Dr. Horner's paper, "Thunderstorm Location by Radio Methods," covered three basic topics:

- The definition of requirements for thunderstorm and lightning location.
- Categories of lightning location systems and some of their features.
- Data handling problems.

The discussion following Dr. Horner's paper is also summarized.

I have been asked to summarize the presentation that Dr. Fred Horner made before Commission VIII of the International Union of Radio Science (URSI), which has just held its XVIIth General Assembly in Warsaw. Commission VIII deals with "Radio Noise of Terrestrial Origin." Dr. Horner sends his regrets for not being able to attend this meeting and make this presentation to you personally. He has asked me to extend to you his wishes for a successful conference and his hope that the scientific output from this meeting will be generally available in the near future.

I will summarize the major points of Dr. Horner's paper, entitled "Thunderstorm Location by Radio Methods," and then mention some of the highlights of the discussion during the session.

Dr. Horner covered three basic topics in his paper:

- The definition of requirements for thunderstorm and lightning location.
- Categories of lightning location systems and some of their features.
- Data handling problems.

Regarding the requirements, Dr. Horner observed that the ultimate requirements should be stated more explicitly than at present by the end users of the data, for example, by weather forecasters and physicists engaged in studies of atmospheric electricity. He noted briefly his own interpretation of some of the many diverse requirements of specialists in the germane disciplines:

- Tracking thunderstorms as an aid to weather forecasting. Only a random sample of discharges need be located, provided they cover all significant centers of thunderstorm activity. Processing delays must be avoided.
- Investigations of the meteorological characteristics of the source discharges. Only small samples are required for some research purposes, and processing delays are usually not critical.
- Research on atmospheric electricity. This may require long-term statistical observations or shorter-term but more comprehensive recordings. Processing delays are not critical.

- Research on radio propagation. Where accurate location of a few selected discharges is needed, more elaborate analysis can be justified.
- Study of ground discharges by power engineers. Cloud-to-ground discharges must be differentiated from other discharges. General surveys do not require high accuracy or rapid analysis, but if studies of the influence of local topography are to be made, high accuracy is needed. A warning system would need immediate processing of data.
- Other operations requiring early warning (aviation, rocket launches, storage of explosives, etc.). Obviously, location techniques based on observations of lightning cannot give warning of the first stroke in a storm.
- Radio noise surveys. These require data on the total activity in an area of the world.

Three categories of lightning location systems can be used: long-range, short-range, and satellite. Taking these in reverse order, for the moment, it was observed that satellites can in principle be used as sensors to monitor the whole world, and should also be considered as a means for providing network control and data collection. The short-range systems discussed were primarily lightning flash counters. However, VHF systems were also mentioned; a great number of short-range detectors would be required to cover the whole world. I will add some comments on short-range and satellite methods later, but most of the discussion at URSI was concerned with the long-range methods that formed the primary focus of this conference. Such systems are capable of operating over some thousands of kilometers and have potential for monitoring large areas (perhaps the whole world) by using only a few stations.

Research on all three categories of systems has been reviewed periodically. A comprehensive review was prepared by Pierce for the Fourth International Conference on the Universal Aspects of Atmospheric Electricity in 1966, and a brief review of short-range lightning flash counters was presented by Horner at that conference. These reviews were published in 1969. More recently, at the XVIth General Assembly of URSI in Ottawa, Jean reviewed long-range and satellite methods; that review was published in 1970. There have been some significant developments since 1969. It is desirable also to keep under review some of the older methods which seem to merit further development even though they have not been the subject of recent work.

Now, I will turn to more detailed discussion of the long-range systems. The discussion of these systems can be further subdivided into the following categories:

- Systems employing cathode-ray direction finders (CRDF) using crossed loops and operating at about 10 kHz.
- Systems employing single-station techniques that can be used as the basis for a network of stations working either independently or in collaboration. A distance-measuring technique must be included, for example, one based on the dispersion of atmospherics at VLF.
- Systems based on time-of-arrival measurements.

CRDF networks have been in routine use by meteorologists for many years in some parts of the world, for example, the British European network shown in Slide 1, while other such nets have been set up for shorter periods for specific purposes. Accuracies at distances up to 2000 km, obtained with baselines of the order of 500 km, are thought to be about 10 percent of the range. Some of these networks have yielded rather disappointing results, however, because of inadequate synchronization facilities or improper use of such facilities. Photographic recordings can mitigate these problems, but long time-delays in processing and analyzing the film records are not normally acceptable for forecasting. Recent research work has concentrated on the development of all-electronic automatic techniques of data transmission and analysis.

To summarize the work on direction finders, the basic techniques are well established, and work is now concentrated on automation. Little work has been done recently on the determination and possible reduction of bearing errors. Indeed, the move towards automation has a tendency to increase these errors, and further practical experience and controlled experiments are needed to show whether any reductions in accuracy are significant. Finally, it would be desirable to know the number and locations of the CRDF instruments currently active.

Regarding single-station location systems, it may first be noted that all such stations include a direction finder. In contrast with the requirement for CRDF networks, the direction finder must be able to resolve the 180-degree phase ambiguity, but this presents no technical difficulty. By far the greatest effort on single-station location has been devoted to methods based upon the spectra of atmospherics at VLF or ELF, and Dr. Horner noted that this was the primary motivation for the present Waldorf Conference. The method adopted by the Heinrich-Hertz Institute relies on the measurement of two parameters to determine the distance to the source of a flash: spectral amplitude ratio (SAR) and group delay-time difference (GDD). It was explained that the SAR is the ratio of the amplitudes of atmospherics in two narrow bands at spaced frequencies, and the GDD is the difference in the times of arrival of impulsive disturbances at two separated frequencies divided by the frequency difference. Extensive tests of the system are under way using cooperating installations in Argentina, Germany, Japan, and the USA. The results have been reported by workers from the Heinrich-Hertz Institute as a mass plot of GDD (which is considered more accurate than SAR) as a function of bearing. The corresponding fixes are plotted on world maps. Dr. Horner showed one example of such a world map taken from a report by Heydt and Frisius, which indicated little activity over Africa (see Slide 2). He expressed doubt as to whether such a map represented worldwide activity comprehensively, and emphasized again the necessity for users to state precisely how they would use such maps, in order to judge whether the maps served their purpose. [Dr. Frisius, in the discussion of the paper, agreed that coverage of the African continent from Berlin was inadequate, perhaps owing to the long overland paths. He stated that Africa would also not be well-covered from the stations in the western hemisphere because of the reluctance of VLF waves to travel in an east-west direction.]

Work in the USSR has indicated that SAR is reasonably satisfactory only for short ranges. More recent work in the USSR by Inkov has been based upon the phase spectrum, and accuracies at 4000 km are said to be about 400 km when compared with CRDF fixes.

A difficulty in these methods is that they are influenced by differences in the spectra of atmospherics as well as by variations in radio propagation characteristics. Also, interpretation can be difficult if more than one storm exists at the same time in the same direction. Despite these difficulties, VLF spectral measurements offer promise of leading to estimates of source distances with sufficient accuracy for some purposes, and, with automatic facilities, of enabling global lightning activity to be monitored in a reasonably comprehensive manner. This method is not yet so well proven as the CRDF network, however, and more tests are needed in which records are obtained on storms whose locations are accurately known by other means. Perhaps the Berlin instrument working in conjunction with the British European network, which can cover North Africa, would offer one possibility for such comparison.

The validity of timing methods was demonstrated by monitoring storms in Europe from North America, by Lewis et al. in 1960, but no follow-up has taken place toward developing an operational system. Time-difference systems have been developed for short-range work at VHF, notably by Proctor in South Africa and by Cianos, Oetzel, and Pierce in the USA. While the technique as so far developed is not suitable for routine measurements on a large scale, it has proved useful for research and for calibration of lightning flash counters.

This brings us to a discussion of ground-based short-range techniques, namely local lightning-flash counters. Recent developments have been characterized by an increase in the number of proposed designs (almost an average of one per year for the last 20 years), but the past three years have shown only marginal progress toward solution of two of the three main problems:

- Establishment of effective range
- Differentiation between ground and cloud discharges.

The solution of the third problem, presentation of the data in the most useful form, depends upon a more precise statement of end user requirements. Despite the shortcomings of counters, a considerable quantity of useful data exists from several networks, and it would be desirable for these data to be collected in a common format to facilitate comparison. This leads naturally to a discussion of what kind of information should be presented. Most data exist in the form of hourly counts; and hourly values for every station represent a large, and perhaps unnecessary, volume of data. It can be reduced if there is no interest in what occurred in a particular hour or day, but presumably any summary presentation needs to show diurnal and seasonal trends. Perhaps a reasonable compromise is to show the statistics of the variations with time of day on a monthly basis, perhaps with a separate presentation of times with exceptionally high activity if this is of interest to any users. For any statistical presentation, the problems of incomplete and possibly erroneous data need to be solved in an agreed way.

Similar comments can be made regarding the data-handling problems from other types of systems (CRDF, VLF spectra, etc.), and the data problems should not be underestimated. They can perhaps be underlined by recalling that the total number of lightning discharges over the world each year is probably between 10^9 and 10^{10}. There is a tendency to assume that a knowledge of the precise location of every one of these discharges is a desirable, if perhaps unattainable, objective. If this is so, then the data-processing procedures for realizable systems need to be based on a knowledge of what users would do with the more comprehensive data if they existed.

A few additional comments on satellite systems are appropriate. Although earth satellites appear at first sight to be excellent platforms for recording the occurrence of lightning discharges, there are serious difficulties in using radio techniques, as explained by Pierce in 1969. First, there is a lack of spatial resolution:

- High-altitude satellites obtain good geographical coverage but suffer inadequate angular resolution.
- Low-orbit satellites move a considerable distance in an observation time interval that is long enough to obtain a meaningful sample of atmospherics.

Another problem is concerned with receiver sensitivity and the background of cosmic noise. Although adequate sensitivities for reception in a low-orbit satellite seem attainable over a wide range of frequencies, there is conflicting evidence on whether atmospherics can be detected at high altitudes.

The optical results of Sparrow and Ney (Nature, 1971) are encouraging, but the small fraction of useful time (near new moon at midnight) is a serious limitation. Nevertheless, the promise of satellites should be pursued, and satellite results should be compared with the results from ground-based measurements when possible, for better assessment of the relative usefulness of the techniques.

Dr. Horner concluded:

1. For locating areas of thunderstorm activity at long ranges there are three systems which need further investigation:

   a. CRDF networks with improved back-up facilities to enable comprehensive data to be collected and processed rapidly. Further work is needed to develop these facilities and to ascertain the optimum locations and separations of stations to provide wide coverage. Part of the study should be concerned with the way in which correlation between the incidence of the recorded atmospherics varies with the separation and the local environment of the stations.

   b. Stations which depend on the measurement of bearing and distance, and which can be used either independently or in a coordinated way. Some automatic recording techniques are well-developed, but more experience and checks against information obtained by other means are needed to assess the accuracies, particularly in the measurement of distance.

   c. Timing methods. These are the least developed, despite their early promise, but are perhaps the most readily applicable, in principle, to an automatic system. Considerable work is needed to assess timing accuracies in a wider range of conditions than were chosen for the early transatlantic tests, to develop the technical facilities, and to determine the optimum locations and separations of stations.

2. For those applications in which it is important to know the distribution of ground discharges, a network designed solely for locating the sources may need to be supplemented by additional facilities. This problem will involve further study if a clear requirement emerges.

3. Simple lightning flash counters, suitable for use on a wide scale, are unlikely to provide all the information which has been specified as a requirement, i.e., accurate maps of the rate of occurrence, with, for some purposes, unambiguous discrimination between ground discharges and others. Development of more complicated systems seems justified as a means for evaluating the performance of simple instruments, but further progress in general surveys is most likely to be made by improvements in reliability and additional experience rather than by the development of new types of instrument.

4. The collection, standardization, and dissemination of lightning counter data need some attention, and agreement should be reached on methods of presenting data in statistical form, taking into account the fact that many records will be incomplete or incorrect. Past experience has shown that faulty operation of instruments can continue undetected for a considerable period, and the analysis of the results is then difficult. More rapid collection and intercomparison of data would help to overcome this problem. Consideration should be given to the desirability of using duplicate instruments on each site as a routine procedure, and reporting data only for those periods when the results agree

within some specified limits. Otherwise, erroneous data may be detectable only on the basis of past experience or by comparison with other nearby stations.

5. Reports on observations with satellite sensors suggest widely varying experience, and apparent discrepancies need to be resolved before the potentialities of the technique can be adequately assessed. Satellites should also be considered an an adjunct to ground-based location systems, to simplify the control of networks and the collection of the data.

6. Clearer statements of the requirements for thunderstorm location are needed for at least two reasons. The first is to enable future research to be concentrated on the most important issues. The second is concerned with the desirability of making the maximum use of the many facilities which already exist. In the present research climate, it is not so easy as at some times in the past for agencies owning facilities to provide support to research projects on a voluntary basis; applications for such support are more likely to be considered favorably if the aims of the research are clearly stated as specifically as possible and exhibit evident scientific merit.

This completes my summary of Dr. Horner's formal presentation.

The lively discussion that followed the presentation of Dr. Horner's paper clarified some aspects of user needs. Professor Mühleisen summarized his view of the needs for research on lightning for use in studies of atmospheric electricity. In studies of the general circulation, anything short of the complete world distribution of discharges to ground would be of limited value. This involves both the problem of location and also that of either differentiating between ground and cloud discharges or recording ground discharges only.

Professor Kimpara considered DF networks to be still the most reliable system of location, technically, but mentioned the work of Sao and others on distance measurement based on automatic measurement of the delay times of slow-tail atmospherics.

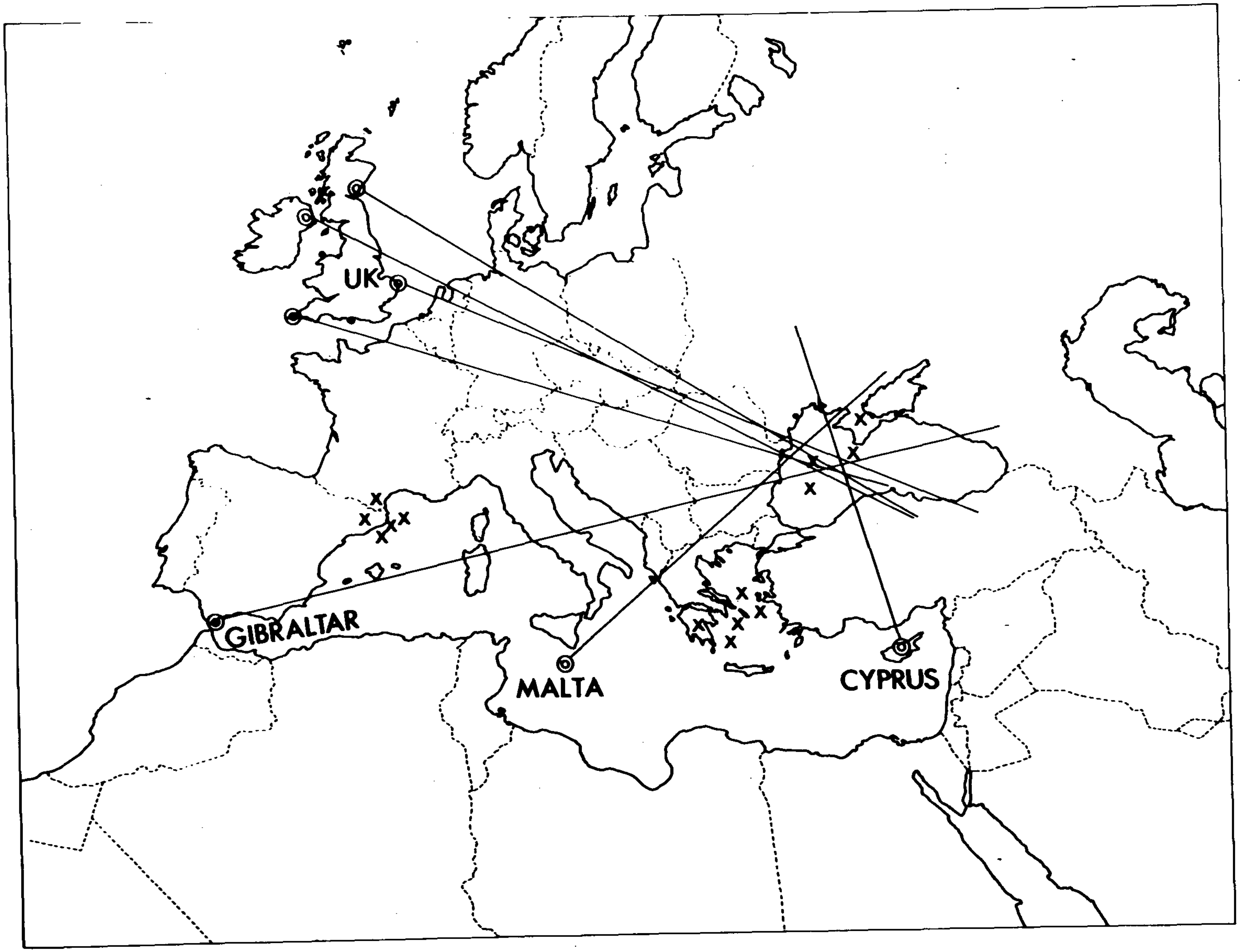
Dr. D. Ll. Jones, following up on Kimpara's comment, showed a comparison of calculations using Williams' source and the measured data of Hepburn (1957) for the slow-tail time of separation from the oscillatory head of the atmospheric as a function of propagation distance. Dr. Jones also mentioned theoretical calculations by Dr. J. R. Wait.

Errors in CRDF bearings were discussed, particularly in relation to the influence of high mountains. These mountains were thought to be the cause of errors in Switzerland, for example, but the mechanism giving rise to the errors was not well understood.

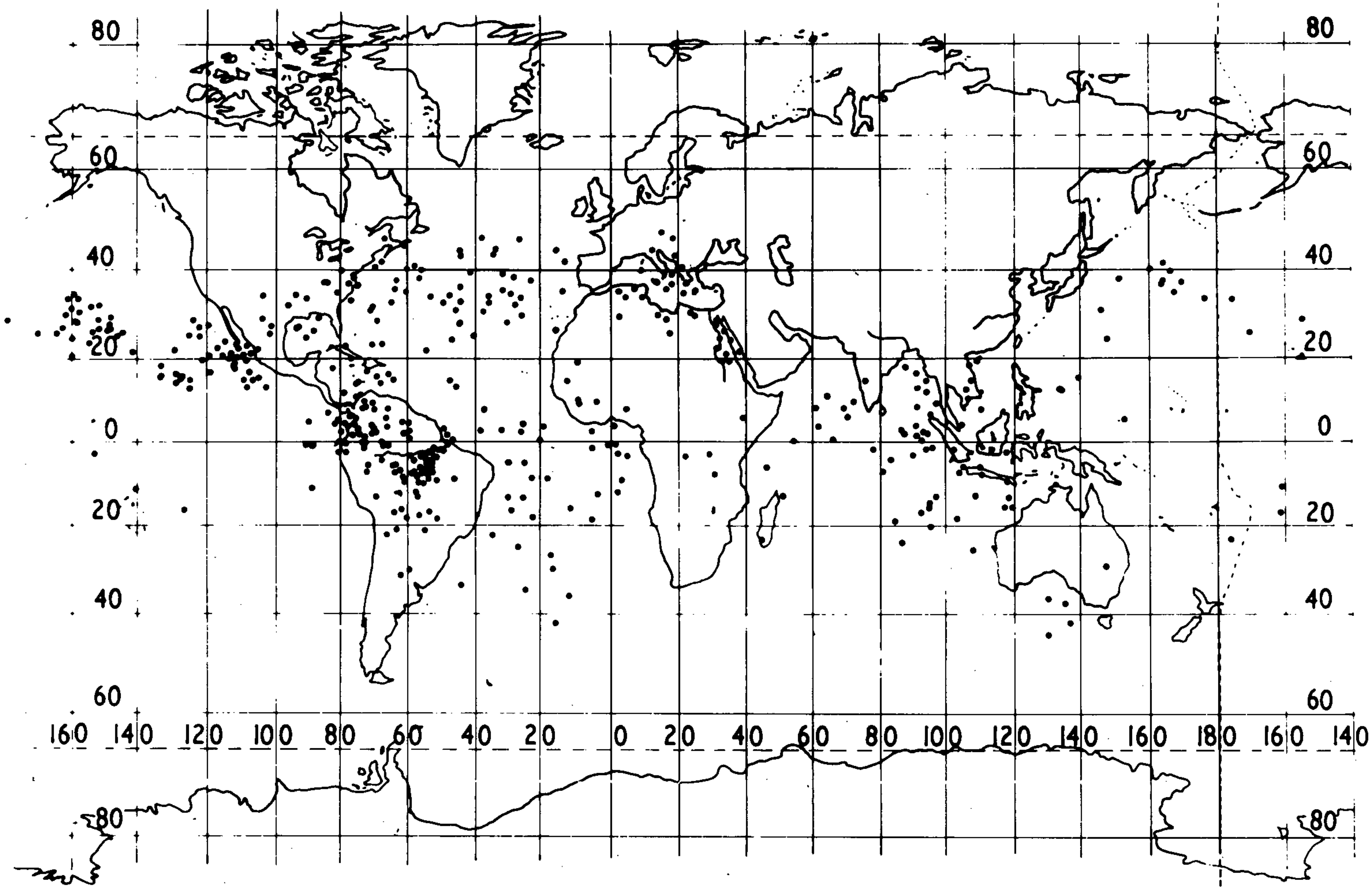
Work in Sweden had been partly directed towards distinguishing ground discharges from others; simultaneous direction-finding at 10 and 27 kHz was said to facilitate the distinction. Gating on the 27-kHz direction finder had been introduced to reduce polarization errors by excluding sky-waves, but it seemed likely to be successful only at short ranges at which the ground wave would predominate.

Dr. Frisius, aided by Dr. Heydt, showed some results obtained by using the GDD method, including a chart of thunderstorm activity as a function of broad geographical area and GMT. Since I am sure this method will receive more discussion during this conference, I will not pursue it further here.

In closing, I would like to mention that Dr. Horner was kind enough to provide copies of the full text of his URSI paper for use during this conference. His paper was prepared to stimulate discussion at the URSI meeting in Warsaw, and I am sure he hopes it will serve that same purpose here.



SLIDE 1 THE BRITISH EUROPEAN CRDF NETWORK



SLIDE 2 MAP OF LIGHTNING LOCATIONS OBSERVED BY USING GDD METHOD

A Review of Techniques and Problems in the Long-Range Localization of Lightning

by

G. Jean
Space Environment Laboratory
Environmental Research Laboratories
National Oceanic and Atmospheric Administration (NOAA)
U.S.Department of Commerce
Boulder, Colorado, 80302

A b s t r a c t:

Techniques and problems in the long-range localization of lightning are reviewed, such as the pros and cons of single versus multiple station systems, groundbased versus satellite systems, real-time versus after-the-fact systems, etc. A wide spectrum of demonstrated technical capabilities and a good working knowledge of propagation appear to offer potential solutions to the long-range m nitoring of thunderstorm activity; however, pre-requisites to the design and implementation of a system are its justification and perfomance specification.

UNCLASSIFIED

Canadian Interest and Activity in Lightning Location

by

R.C. MURTY

University of Western Ontario

London, Canada

Canada has a natural interest in lightning location for a considerable time. Considering that the forest products contribute a large portion to the national economy it is hardly surprising. The importance of lightning location can be seen from the following two tables[1]:

TABLE 1

Forest fires, by cause, 1963 and 1964

Cause	1963		1964	
	No.	%	No.	%
Totals, Man caused (including unknown)	5319	69	4955	71
Lightning	2351	31	1989	29
Total	7670	100	6944	100

TABLE 2

Forest fire losses, 1963 and 1964, compared with ten year average 1954-63

Item	1963	1964	Average 1954-63
Total fires	7,670	6,944	6,142
Area burned (acres)	470,001	2,993,290	2,388,025
Average size of fire (acres)	61	431	389
Estimated values destroyed ($)	4,265,926	6,522,947	13,605,475
Cost of fire fighting ($)	4,772,714	4,430,041	5,661,610
Totals: damaged and fire fighting costs ($)	9,038,640	10,952,988	19,267,085

It is interesting to note that in some years, for example in 1963 and also in 1966, the cost of fire fighting exceeded the estimated values destroyed. However, in general the process is reversed and it is safe to say that on an average the cost to Canada is about 20 million dollars in total damage and fire fighting. In 1964, lightning accounted for 29% of all forest fires and 80% of the total area burned. It is reasonable to assume that on an average, lightning is the cause of 20-25% of all forest fires damaging in excess of 50% of forests.

The pulp and paper industry[2], the forestry departments, the Meteorological Branch (now changed to Atmospheric Environment Service), the Hydro companies all have a vested interest in lightning location.

In 1964 the Meteorological Branch, Department of Transport, Canada approached a number of universities for a survey on lightning detection. In 1965 the author of this article from the University of Western Ontario was given the task of preparing a comprehensive survey on lightning detection and to make a set of recommendations. A report "Lightning Detection Studies" was submitted in 1966 to the Meteorological Branch[3].

A five year contract for research into the development of equipment and techniques for the detection and tracking of lightning strokes and their differentiation into types or classes was awarded to the University of Western Ontario in 1967-68. Under the direction of the author, work was undertaken to test lightning counters, VLF and VHF direction finders and microbarograph networks. At the same time the meteorological Branch developed Atmospheric Electricity Research in its cloud Physics group. Work on VLF direction finding networks and the development

Present status of the study on direction finding and location of atmospherics at the Research Institute of Atmospherics

K. SAO

A. IWAI

T. TAKEUTI

T. KAMADA

Research Institute of Atmospherics, Nagoya University, Toyokawa, Aichi, Japan

Abstract

Functions of three locating equipments operating at R.I.A. including Atmospherics Analyser developed by the Heinrich-Hertz-Institute are briefly compared in this paper. Further studies as to the improvements for respective methods will be made by cooperative observations between them.

There exist three kinds of locating equipments at the Research Institute of Atmospherics at the present time. They are Sferics Fix Network (SFN) with three stations developed several years ago, Atmospherics Analyser (AA) introduced through German scientists a few years ago and the Locator by Single Station (LSS) which is reported in detail by Sao(Waldorf Conf. paper 44, Washington D.C., Sept. 1972). The present paper presents some characteristics of three types of location and a sample of the tests of the simultaneous observations carried out on 6 th August 1972. This is, indeed, a preliminary report because continuing improvements for each apparatus are being made except for the Atmospherics Analyser. Finally, general aspects of bearing and frequency of received atmospherics observed at Syowa Station in Antarctica are briefly stated.

1. Sferics Fix Network (S F N)

This is a conventional triangulation method, consisting of three stations (Moshiri, Sakushima and Kagoshima Observatories) which are situated at both extremities and near the center of Japan. The triangulation is fixed by a computer from the data recorded simultaneously at each station. Here, the identification of atmospherics at three stations is ascertained by only the time received, thus high accuracy of electronic clocks is required. And, since the bearing of received atmospherics are measured digitally, it is natural that the calibration of bearing must be made carefully. By operating the network, location maps will be obtained periodically to collect abundant data to investigate the relation between the meteorological factors and thunderstorms. However, the difficulty is the impossibility of fixing atmospherics originating along the base line of these three stations, which coincides with the most active region of thunderstorms in Asia. Thus, it can be said that the most reliable fixes are obtained only for atmospherics originating in China or Siberia. Attempts to obtain fixes during the summer season sometimes fails because of frequent local thunderstorms at each station, thus it appears to be necessary to improve the triangulation technique for the typhoons.

2. Atmospherics analyser (A A)

Observations of source location in the Far East are being made on the roof of the building of the R.I.A. by the Atmospherics Analyser developed by Heinrich-Hertz-Institute. This apparatus has its own merit of location by single station, and global geophysical aspects such as global circulit or general circulation and the nature of atmospherics originating from the typhoon or frontal lines will be investigated by the use of this apparatus. One main difficulty is how to display the realistic distribution of sources, and thus digital representation of sources rather than by photographic methods is currently discussed. The principle of this apparatus is the dispersion involved in the propagation of VLF components of atmospherics. There is, therefore, great difficulty in locating atmospherics of the so-called ionospheric reflection type waveforms originating within approximately 1500 Km during the summer season.

3. Locator by Single Station (L S S)

Details are not written here because this apparatus is stated elsewhere (refer to Sao, paper 44). This is also one of the dispersion methods, but the frequencies adopted are different from the Atmospherics Analyser. This is based on the difference of group velocities between VLF and ELF (slow tail) components, thus the atmospherics originating within approximately 1000 Km should be excluded because of inadequate mode excitation. An important matter to be studied would be the ionospheric perturbations by height and conductivity which give some errors on the estimation of traversing distances. Another anxiety is for the term corresponding to the pulse width which is assumed to be constant at the present time. However, the remarkable merit of this apparatus is not only the single station technique but the separation of ground discharges from inter-cloud discharges. Thus, this apparatus is convenient for investigating the difference of genesis of thunderstorms between land and sea discharges, between daytime and nighttime and between discharges to high mountains and to low plains. Improvements of electronic circuits are now being made to reduce the scatterings of distribution of sources and to stabilize the whole system.

A sample of the test of cooperative observation made by these three locating equipments is shown in Fig.1. Although locations by Atmospherics Analyser show wide distributions of sources, and no distribution of mark ⊙ exist approximately along the baseline of Sferics Fix Network, Fig.1 would be the present status of the study on direction finding and location of atmospherics at R.I.A.

As mentioned above, although these three types of equipment are in operation, fundamental problems on the long wave propagation such as refractions or polarisations are not yet fully studied. Since there is no method which is, indeed, standard for locations, it can be said that they are complementary to each other at the present time. Hence, it would be a good policy to do research independently on appropriate objectives, paying attention to the probable errors involved with each apparatus. Cooperative observations will be made intermittently (for example every season)to improve functions of the respective apparatus by comparing the results of locations obtained.

4. Another matter to be mentioned here is the arrival direction and occurrence frequency of atmospherics at Syowa station in Antarctica. The observations for distant sources of atmospherics were carried out at a frequency of 10 KHz. The principal results obtained were such that A) the arrival direction of atmospherics at Syowa station is mostly the north in almost all seasons, suggesting the active thunderstorm area of Central and South Africa, and B) the monthly averages of diurnal variation of the frequency of atmospherics in each azimuth were obtained as is shown in Fig. 2. The above results obtained from the diurnal variations of the frequency of atmospherics at each azimuth seem to indicate that in Antarctica there is a fair chance of watching the diurnal thunderstorm activity from distant sources which are distributed along the equatorial zone in every season.

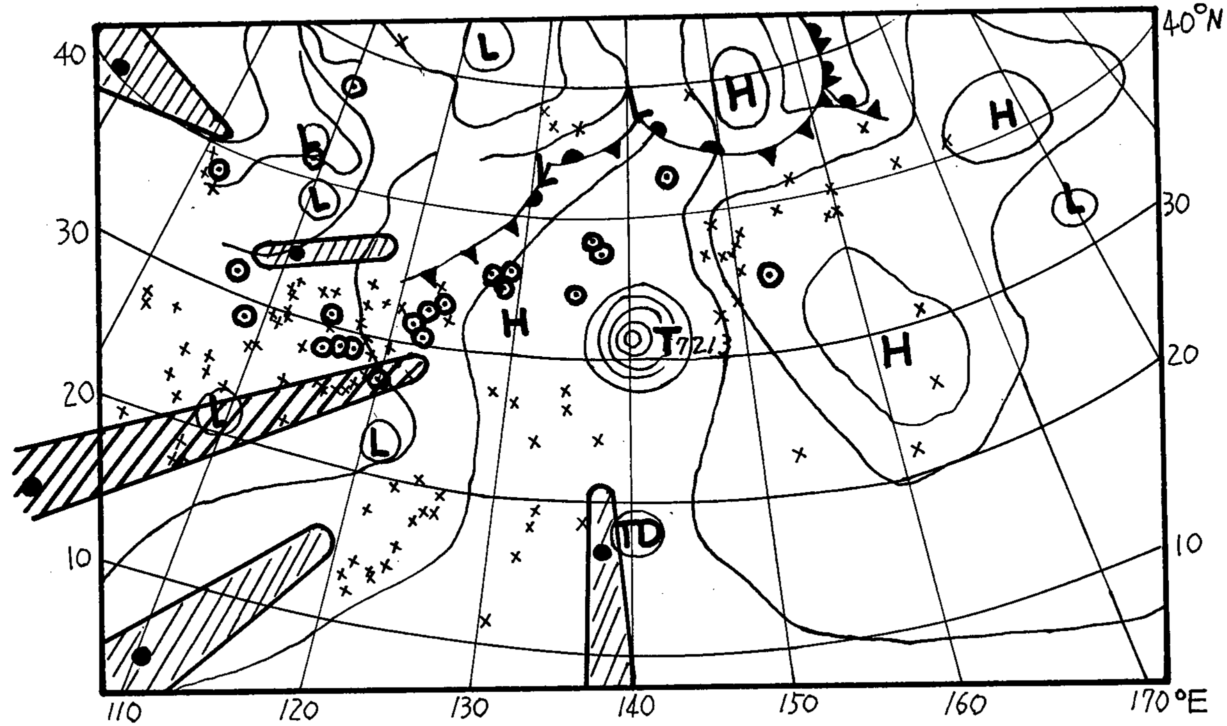


Fig. 1 A sample of results of respective locations of atmospherics at 21 hour JST 6, Aug. 1972

(⊙ S.F.N., A.A., X L.S.S.)

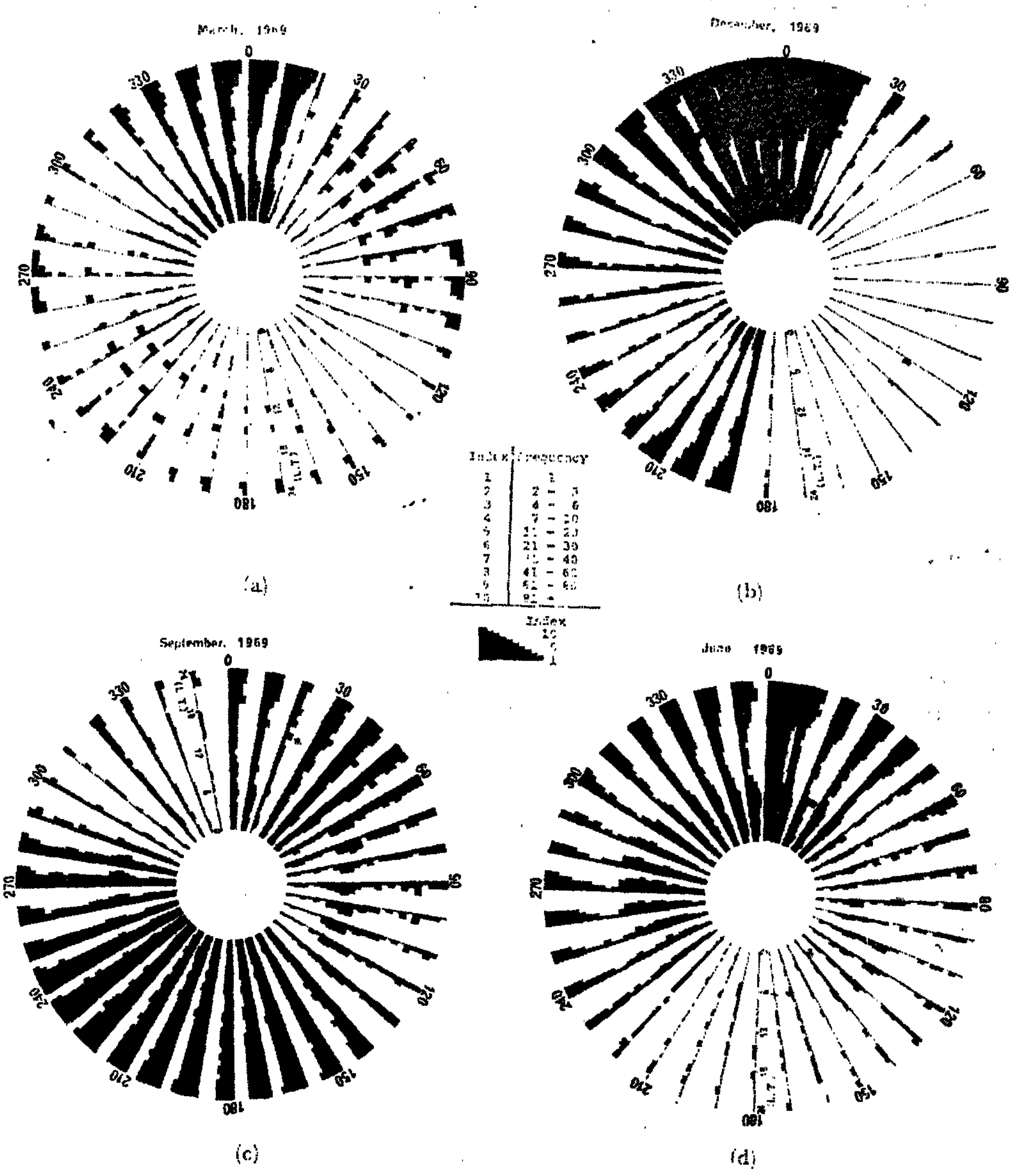


Fig. 2 Monthly averaged diurnal variation of frequency of atmospherics in each azimuth at Syowa Station in Antarctica (from March 1969 to January 1970)

CRITICAL COMPARISON BETWEEN SINGLE STATION TECHNIQUES OF LOCATING THUNDERSTORM AREAS

by

Hans Volland

Astronomical Institutes
Bonn University
Bonn, W. Germany

The most widely used and least complicated method, from a theoretical point of view, to locate thunderstorms is the direction-finding method in which three or more stations are spaced on long baselines with at least 1000 km between them. This method needs expensive communication networks to observe simultaneously single lightning discharges. The interpretation of these measurements is straightforward. The errors involved are bearing errors due to the orography and/or the anisotropic and inhomogeneous ionosphere. The disadvantages of this method are the limited range of application (which is of the order of the baselines) and the difficulty in obtaining enough data to do a statistical analysis.

The second multistation technique is based on the difference in the times of arrival of an atmospheric at different stations. Although this technique is in principle of great accuracy, the difficulties involved here are similar to those of the direction-finding method: great expenditure, limited range of application if only a few stations are available, and inaptitude for a statistical approach.

Relatively inexpensive methods to locate distant thunderstorms are single station techniques. Their only source of information is the angle of arrival and the wave form of the vertical electric field strength of a single atmospheric. It is well known that from a Fourier analysis of such a wave form a product

$$G B = g \; b \; \exp\left\{ j(\Psi + \Phi) \right\} \qquad (1)$$

can be derived where G is the source function of the atmospheric with magnitude g and phase Ψ, and B is the transmission function of the wave guide between earth and ionosphere.

A very old and common method is to measure the wave form of successive atmospherics with a broad band receiver and to do a Fourier analysis for each individual wave form. This gives the most complete information available from an atmospheric. If the transmission function B is known it is then possible to relate uniquely the observed atmospheric to a certain distance. Together with the measured angle of arrival, the origin of the atmospheric is then given.

The transmission function B is very complicated, depending on time, angle of arrival, distance, and frequency. However, the VLF-theory is far advanced, and B can in principle be uniquely determined (see e.g. the textbooks by Wait (1962) and Galejs (1972)). On the other hand, it is well known that the source functions vary in a wide and unpredictable range. Therefore in order to locate thunderstorms with the help of atmospherics, the evaluation of the data based on a statistical approach is absolutely necessary. From such statistical data reduction one obtains mean values $\overline{g\,b}$ and $\overline{\Psi + \Phi}$ instead of equ. (1), and probability distributions of the scattered data which might now be expected to be predictable.

The above-mentioned wave form analysis is not suitable for such a statistical method because this would become very time consuming, and moreover, a complete wave form analysis contains much abundant information unnecessary for the purpose of thunderstorm locating. In fact, because of the known behavior of the transmission function B in equ. (1), it is in most cases sufficient to evaluate the function in (1) at a few discrete frequencies in order to obtain enough information about the distance of the source.

One of the more appropriate methods is based on the measurement of the difference in the times of arrival between the VLF-pulse and the ELF-slow tail of the wave form. Pierce in this conference read a paper by Sao where such a method has been used. This method works reasonably well because the wave guide between earth and ionosphere has two windows in which electromagnetic wave propagation is least attenuated. One window is located within the VLF-range near 15 kHz where the 1^{st} mode predominates. The other window is within the ELF-range near 2 kHz where the 0^{th} mode is the dominant carrier of electromagnetic energy. From electromagnetic wave theory one can determine the difference in the times of arrival of both these modes and obtains a simple relationship between distance and time of arrival (Wait, 1962). However, the time of arrival depends on frequency as well, and the frequency where minimum attenuation occurs shifts with distance. Moreover, the onset of the VLF- and ELF-pulses, respectively, of the wave form depends on the highly variable phase Ψ of the source function in (1). Therefore the output data obtained from this method are ill adjusted to the theory.

The HHI-analyser developed in BERLIN measures the difference in the times of arrival of two well-defined adjacent frequencies within the lower VLF-range. That means the only number subtracted from the available information in (1) is the second derivative of the phase with respect to the frequency f at one particular frequency f_o:

$$\left.\frac{\partial^2(\Psi+\Phi)}{\partial f^2}\right|_{f=f_o} \propto \rho \qquad (2)$$

which is proportional to the distance ρ if only the 1^{st} mode contributes to the wave propagation, and which is immediately available at the output of the receiver without further data reduction. Thus that method provides the least redundant information necessary for the purpose of locating thunderstorms, and there remains sufficient capacity for receiver (and observer) to measure (and evaluate) every atmospheric exceeding the threshold of the receiver, or to repeat the measurement at other frequencies.

It should be emphasized again that any single station technique has to deal with the same available information given in (1). The only difference between the various methods is the different preparation of the data so that they are optimally adjusted to the theory and, moreover, appropriate for a statistical analysis.

References

Galejs, J., "Terrestrial propagation of long electromagnetic waves", Pergamon Press, Oxford, 1972

Wait, J.R., "Electromagnetic waves in stratified media", MacMillan, New York, 1962

An Instrument to Digitize the Individual Sferics Parameters Provided by the Atmospherics Analyzer at Waldorf, Maryland

Robert V. Anderson
Naval Research Laboratory
Washington, D. C. 20375

Abstract

Information from the Atmospherics Analyzer has been available only in the form of statistical averages whether the data are in the form of dot clusters on photographic film or frequency histograms of received impulses as functions of time or azimuth. Occasions have often arisen when such a degree of averaging masks the required information.

An instrument system is described which records the values of azimuth, spectral amplitude, spectral amplitude ratio, group delay time difference, and time of receipt on magnetic tape in a format which permits either digital or analog playback to be made. The system is shown to be simple and relatively inexpensive to build.

Typical data recordings obtained by the recording system are shown. Some analyses are outlined which show promise and which would be impossible without the detailed information inherent in the magnetic recordings.